AMERICAN JOURNAL OF PHYSICAL ANTHROPOLOGY 106:349–359 (1998)

Aging Bone Score and Climatic Factors

VICTOR BELKIN,[1*] GREGORY LIVSHITS,[1] ITZHAK OTREMSKI,[2]
AND EUGENE KOBYLIANSKY[1]
[1]*Department of Anatomy and Anthropology, Sackler Faculty of Medicine, Tel-Aviv University, Tel-Aviv, Israel* [2]*Ichilov Hospital, Department of Orthopaedics, Tel Aviv, Israel*

KEY WORDS bone aging; climate; human populations

ABSTRACT Hand radiograms for osseographic assessment of bone aging status were taken from more than 7,500 individuals residing in 31 different localities and belonging to 20 ethnic groups. Multiple regression analysis was used to evaluate possible associations between bone aging parameters and several climatic factors, to wit: hours of daylight in January and July, average monthly humidity and partial vapor pressure in January and July, and one climatic index pertaining to comfort conditions in life, namely, the Bioclimatic Index of Severity of Climatic Regime. Multiple regression analysis clearly pointed to significant correlations between climatic characteristics and indices defining the relative rate of bone aging in humans; it also evinced an independent contribution of July's humidity and January's mean temperature to earliest age at which first signs of bone aging can be found. In sum, there are grounds for concluding that temperature and humidity are key factors in triggering initial bone changes in individuals within the human populations prone to environmental effects. The combination of humidity and temperature with other factors which reflect the sharpness of the interseasonal differences in climatic conditions predispose the populations to early onset of bone changes. Am J Phys Anthropol 106:349–359, 1998.

It is widely accepted that various characteristics of the rate of bone aging, such as bone mineral density and radiogrammetry, which relates to cortical bone thickness are subject to substantial ethnic variation (see reviews of Pollitzer and Anderson, 1989; Plato et al., 1994). Our recent study of another measure of bone aging, namely, bone aging scores (OSS) has shown that it, too, is amenable to strong ethnic and geographical variation (Kobyliansky et al., 1995). However, in a more recent investigation of bone aging among 31 selected populations of Eurasia, we concluded that ethnic differences per se cannot account for the observed variations but, rather, there are also correlations between OSS and certain climatic–geographic factors (Livshits et al., 1996). Thus, for instance, parameter T_m, which estimates average population age when the first age-dependent changes in bone appeared, showed no correlation with ethnic differences as assessed by linguistic, morphological, or blood genetic differences. However, it showed significant multiple correlation with geographical coordinates, summer–winter temperatures, and the annual precipitation. These findings, as well as numerous other studies that indicated the influence of climatic factors on skeletal morphogenesis of people living in specific climatic areas (Dickinson, 1970; Alexeeva, 1977; Beals et al., 1983, 1984; Melton and Riggs, 1987; Pavlovsky, 1987; Pollizer and Andersen, 1989; Walter, 1992; Goldberg et

*Correspondence to: Victor Belkin, Department of Anatomy and Anthropology, Sackler Faculty of Medicine, Tel-Aviv University, Ramat-Aviv, Tel Aviv, Israel, 69978. E-mail: vbelkin@post.tau.ac.il

Received 16 June 1997; accepted 20 February 1998.

al., 1993; Beall, 1994; Pavlovsky and Kobylansky, 1997), have pointed out the need for a more painstaking analysis of the correlation between climatic characteristics and bone aging patterns. In this article, we explore the impact of several aspects of climate, such as monthly temperature, atmospheric pressure, dominant wind direction, precipitation, altitude, daylight duration, humidity, and comfort level in January and July, on bone health status.

MATERIALS AND METHODS

The data for the present study were collected from 31 geographic locations in the former USSR, Egypt, Israel, and India (Kobyliansky et al., 1995). The total sample included 3,611 men and 3,949 women, whose age ranged from 18 to 99 years. However, because Kobyliansky et al. (1995) found a highly significant correlation between parameter estimates in the rate of bone aging between men and women from the same population, only data on men were analyzed here (Appendix A), sufficient to enable comparison of the present findings with previous ones (Livshits et al., 1996). To evaluate individual bone age scores (OSS), we performed an analysis of the hand roentgenograms in dorso-palmar projection (Pavlovsky, 1987; Pavlovsky and Kobyliansky, 1997). Roentgenograms of the hand were taken in the postero-anterior position with the X-ray source 60 cm above. These were exposed for 5–10 sec at 100–150 mA without intensifying screens at 50 kV. To evaluate individual OSS scores, we recorded occurrence of the following: 1) osteophytes in the periarticular region of the bone and at sites of muscle–tendon attachment; 2) manifestation of osteoporosis; 3) signs of osteosclerosis, and 4) nontraumatic articular deformities. Only bones of the 2nd to 5th fingers were examined; those of the 1st finger do not project directly in roentgenography and therefore were not studied. For each OSS estimate, merely the presence of a given element, but not its level of development, was recorded. Our study of more than 7,000 individuals showed that OSS usually rank between 0 (no signs of involutive changes in the bone) and 40 (the highest observed rank with the most advanced stage of bone changes) (Pavlovsky and Kobyliansky, 1997). The relationship between OSS and age for men and women separately in the total sample is shown in Figure 1. As seen, though their relationship is well fitted by linear correlation ($r > 0.78$), the observed relationship is not merely linear. Till about age 22, no visible changes occurred in the hand bones. However, since that age the changes accumulate almost linearly with age. The two stages stochastic model fits will this pattern of age dependent changes in OSS. A detailed description of our methodology of OSS assessment and of the parameter estimates used in the stochastic model providing to fit OSS changes in every population under the present study has been given previously by Kobyliansky et al. (1995). The applied stochastic model contained the following parameters:

1) t_0 — earliest age at which first signs of bone aging can be found;
2) q — individual probability of revealing first signs of involutive bone changes assuming $t_i \geq t_0$;
3) b — regression coefficient characterizing the rate of bone changes per chronological time unit (per year);
4) T_m — population mean age when the first visible bone changes occur.

Additionally, we introduced the new indices of bone aging which presumably are connected with environmental factors:

$$\text{Rate of bone aging (RBA)} = T_m - t_0 \text{ and}$$

$$\text{Relative rate of bone aging (RRBA)} = (T_m - t_0)/T_m.$$

These indices characterize time intervals which determine the population rate of bone aging onset and therefore reflect the group level bone resistance against environmental involvement in the visible process of bone destruction. Correlation between estimated bone aging parameters and their derivatives are shown in Table 1. As can be seen, parameters t_0, q, and b are independent of one another and their derivatives are intercorrelated, in particular, RBA and RRBA. Hence, they cannot be considered independently. Yet the correlation between T_m, RBA, and RRBA and of each of them with the estimated parameters are only moderate.

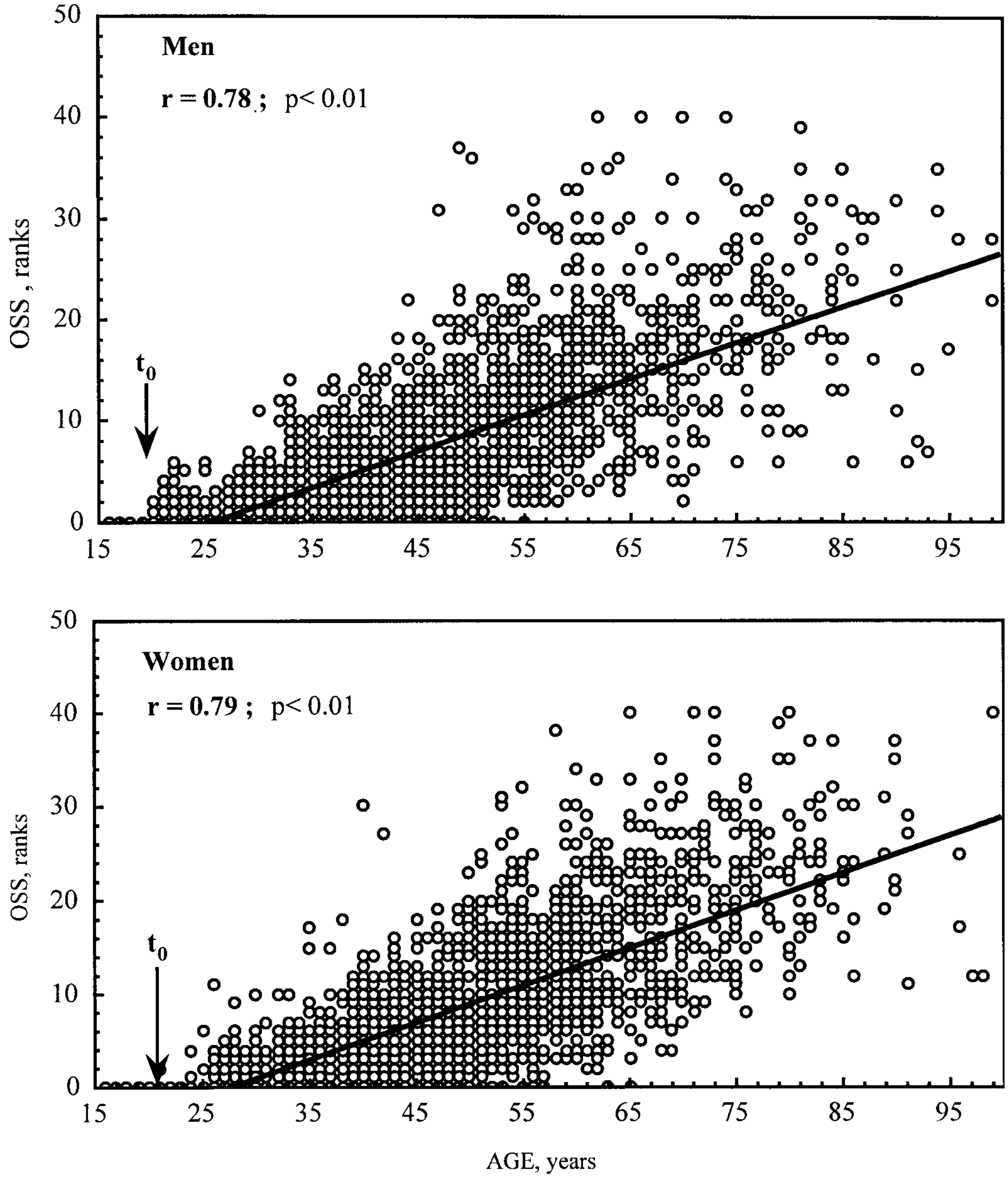

Fig. 1. Age-dependent changes in hand bones OSS in total sample of men (n = 3,611) and women (n = 3,949). t_o= estimated earliest age at which first signs of bone aging can be found;r= linear correlation between OSS and age in the entire sample, according to sex.

Data on geographical coordinates (LATID and LONGT) and on climatic factors were also collected for each population (Appendix B). Climatological data included mean monthly temperature in January (TMPJN) and in July (TMPJL), mean monthly atmospheric pressure in January (PRSJN) and in July (PRSJL), direction and frequency of the dominant wind in January (DIRJN and WNDJN) and in July (DIRJL and WNDJL), mean annual precipitation (PRCPT), and altitude (ALTTD).

To explore the complex relationships between bone aging parameters and climatic–

TABLE 1. Matrix of correlation coefficients between age score parameters and their derivatives

	t_0	q	b	T_m	RBA	RRBA
t_0	1.00					
q	0.02	1.00				
b	0.04	−0.15	1.00			
T_m	−0.61*	−0.52*	0.08	1.00		
RBA	−0.02	−0.66*	0.05	0.67*	1.00	
RRBA	−0.43*	−0.72*	0.05	0.43*	0.94*	1.00

t_0/earliest age at which first signs of bone aging can be found; q/individual probability of revealing first signs of involutive bone changes assuming $t_i > t_0$; b/regression coefficient characterizing the rate of bone changes per chronological time unit; T_m/population mean age when the first visible bone changes occur; RBA/rate of bone aging = $T_m - t_0$ and RRBA/relative rate of bone aging = $(T_m - t_0)/T_m$.
* $P < 0.05$.

geographical characteristics used in the previous article (Livshits et al., 1996), we introduced the day duration (hours) in January and July (DAYJN, DAYJL) and the monthly mean humidity (partial vapor parcel pressure; hPa) in January and July (VPJN, VPJL; Appendix C). This information was obtained from Monthly Climatic Data for the World, 1980–1990. In addition, one climate index pertaining to "comfort" was added to the analysis, namely, Bioclimatic Index of Severity of Climatic Regime (BISCR). This measure was originally introduced by Belkin (1992), who provided a detailed explanation of the principles underlying the formulation, calculation, and application of this index. It will suffice to state here that the BISCR it is an empirical "comfort" measure reflecting the severity of climatic influence on the human organism at specific levels of activity. The gradations of comfort selected as a scale for this index were: 1) Comfortable temperature −22°C, with extreme positive at 60°C and extreme negative at -90°C (-83.8°C as recorded at the Vostok Station in Antarctica); 2) Comfortable pressure—1016 hecto-Pascal's (hPa), with extreme low pressure at 266 hPa (corresponding to that at the peak of Mount Everest); 3) Comfortable wind speed—calm, with extreme at 50 m/s; 4) Comfortable relative humidity—50%, with extremes at 0 and 100%.

The expression for the BISCR is:

$$\mathrm{BISCR} = \frac{T_i(P - 266)(1 - 0.02V)}{r_i{*}S{*}75}, \quad (1)$$

where T_i = temperature coefficient; P = barometric pressure (hPa); V = wind speed (m/s); r_i = relative humidity coefficient; and S = coefficient of solar radiation. Under ideal conditions, BISCR = 10; for maximal extremes of all terms in the equation BISCR = 0. Let us now, briefly, define the terms introduced into Formula 1.

The temperature coefficient, T_i, is defined as:

$$T = \begin{cases} 1 - 0.0089(22 - T), & \text{if } T < 22°C; \\ 1 - 0.0263(T - 22), & \text{if } T > 22°C; \end{cases}$$

The influence of the humidity factor on the magnitude of the BISCR index and, correspondingly, the discomfort effect on humans is estimated to be about 30% (Belkin, 1992). Hence, the coefficient of relative humidity, r_i, can be determined from

$$r_i = \begin{cases} (1 + 0.6)\dfrac{r - 50}{100}, & \text{if } r > 50 \text{ percent}; \\ (1 + 0.6)\dfrac{50 - r}{100}, & \text{if } r > 50 \text{ percent}; \end{cases}$$

Introduction of the coefficient of solar radiation, S, is due to the necessity to indirectly assess the discomfort caused by an altitudinal increase of direct solar radiation at elevations above 2,000 m.

$$S = \begin{cases} 1, & \text{if } H < 2000\text{m}; \\ 1 + 0.45\dfrac{(H - 2000)}{1000}, & \text{if } H > 2000\text{m}; \end{cases}$$

For the present study, relative r_i humidity was calculated using VPJN, VPJL, and air temperature (Smith, 1978). The BISCR was calculated separately for January (BISCRJN) and for July (BISCRJL). The differential parameter DifBISCR = BISCRJL - BISCRJN, reflecting the extent of interseasonal differences in the climatic conditions, was also included in the analysis.

Statistical analysis

Parametric and nonparametric correlation analysis (Spearman) and multiple regression analysis were used for evaluation of the relationship between climatic factors and their possible contribution to bone aging

TABLE 2. Correlation coefficients between bone aging parameters[1] and some climatic factors and their derivatives[2]

Climatic factors		Bone aging parameters				
		t_0	q	b	T_m	RRBA
Longitude	Spearman	0.358*	0.160	0.322†	0.225	−0.227
	Pearson	0.366*	−0.067	0.305†	0.162	−0.226
DAYIL	Spearman	0.281†	0.369*	0.092	−0.127	−0.454*
	Pearson	0.204	0.188	0.122	−0.069	−0.339†
TMPJN	Spearman	−0.260	−0.357*	−0.069	0.093	0.446*
	Pearson	−0.283†	−0.104	−0.165	0.055	0.400*
TMPJL	Spearman	−0.110	−0.197	−0.209	0.125	0.234
	Pearson	−0.095	−0.115	−0.221	0.087	0.223
VPJN	Spearman	−0.329†	−0.095	−0.322†	−0.199	0.197
	Pearson	−0.433*	−0.049	−0.295†	−0.258	0.271
VPJL	Spearman	−0.576**	−0.258	0.082	−0.205	0.405*
	Pearson	−0.533**	−0.153	−0.159	−0.257	0.376*
BISCRJL	Spearman	0.021	0.389*	0.058	−0.284†	−0.381*
	Pearson	0.112	0.372*	0.092	−0.253	−0.429*
DifBISCR	Spearman	0.128	0.427*	0.056	−0.264	−0.454*
	Pearson	0.089	0.209	0.066	−0.286	−0.424**

[1] t_0/earliest age at which first signs of bone aging can be found; q/individual probability of revealing first signs of involutive bone changes assuming $t_i > t_0$; b/regression coefficient characterizing the rate of bone changes per chronological time unit; T_m/population mean age when the first visible bone changes occur; RRBA/relative rate of bone aging = $(T_m - t_0)/T_m$.
[2] DAYJL/daylight duration (hours) in July; TMPJN/mean monthly temperature in January; TMPJL/mean monthly temperature in July; BISCR/bioclimatic index of severity of climatic regime; BISCRJL/the BISCR for July; DifBISCR/the differential parameter = BISCRJL − BISCRJN, reflecting the effect of interseasonal differences in the climatic conditions; VPJN/monthly mean humidity (partial vapor parcel pressure; hPa) in January; VPJL/monthly mean humidity (partial vapor parcel pressure; hPa) in July.
† $P < 0.10$.
* $P < 0.05$.
** $P < 0.01$.

parameter differences between samples (Sokal and Rohlf, 1981).

RESULTS

Table 2 provides pairwise correlation coefficients for each of the bone aging parameters and their derivatives and climatic factors. Climatic factors and indices that showed no significant correlation with any of the bone age characteristics are not presented in the table. Two types of correlations, namely, Pearson's product moment and Spearman's coefficient of rank order correlation, are given in each instance. Due to a relatively small number of degrees of freedom, very high correlations were not expected a priori. We therefore chose $P <$ 0.10 as a critical value. Under this condition, the correlation was considered significant and apt for further multivariate analysis if it met two additional criteria, namely, that the sign and magnitude of both types of correlations were comparable and similar in both sexes, as adopted also in our previous study (Livshits et al., 1996).

The magnitude and direction of correlations were comparable in all instances, as shown in Table 2, indicating potential relationships between each of the bone aging characteristics and several climatic factors. Of special interest, owing to their relatively high values, are the correlations between the t_0 and RRBA and the average humidity in July. Note also the substantial correlations between RRBA (or RBA) and daylight duration in July, mean temperature in January, bioclimatic index in July, and the difference in BISCR estimates in the winter and summer months. It is worthy of mention that the original parameter estimates of bone aging, correlated with a smaller number of climatic factors, and the degree of correlations was more modest than with indices of rate of bone aging.

The indices of rate of onset of bone aging proved the most sensitive feature of climatic effect and we therefore attempted to ascertain the independent contribution of each of the potential predictor factors, inasmuch as strong correlations were detected between

TABLE 3. Matrix of correlation coefficients between studied climatic factors in 31 geographic localities

	Longitude	DAYJL	TMPJN	TMPJL	VPJN	VPJL	BISCRJL	DifBISCR
Longitude	1.00							
DAYJL	0.52*	1.00						
TMPJN	−0.70*	−0.73*	1.00					
TMPJL	−0.56*	−0.87*	0.68*	1.00				
VPJN	−0.48*	−0.58*	0.67*	0.59*	1.00			
VPJL	−0.63	−0.62*	0.59*	0.51*	0.52*	1.00		
BISCRJL	0.02	0.47*	−0.23	−0.48*	−0.23*	−0.21	1.00	
DifBISCR	0.56*	0.75*	−0.87*	−0.77*	−0.54*	−0.56*	0.58*	1.00

DAYJL/daylight duration (hours) in July; TMPJN/mean monthly temperature in January; TMPJL/mean monthly temperature in July; BISCR/bioclimatic index of severity of climatic regimen; BISCRJL/the BISCR for July; DifBISCR/the differential parameter = BISCRJL − BISCRJN, reflecting the effect of interseasonal differences in the climatic conditions; VPJN/monthly mean humidity (partial vapor parcel pressure; hPa) in January; VPJL/monthly mean humidity in July.

TABLE 4. Multiple regression analysis of bone-aging parameters[1] on climatic factors[2]

Independent variables	$b \pm SE_b$	Partial correlation	R-Square change	F	P
1. *Dependent variable—parameter RBA*					
DifBISCR	−2.366 ± 0.903	−0.437	0.191	6.582	0.014
2. *Dependent variable—parameter RRBA*					
DifBISCR	−5.344 ± 2.115	−0.425	0.180	6.380	0.017
3. *Dependent variable—parameter t_0*					
VPJL	−0.628 ± 0.172	−0.566	0.284	11.537	0.002
TMPJN	0.155 ± 0.116	0.206	0.042	1.768	0.094
Multiple $R^2 = 0.374$, $p = 0.004$					
4. *Dependent variable—parameter q*					
BISCRJL	0.061 ± 0.028	0.372	0.138	4.656	0.039

[1] t_0/earliest age at which first signs of bone aging can be found; q/individual probability of revealing first signs of involutive bone changes assuming $t_i > t_0$; b/regression coefficient characterizing the rate of bone changes per chronological time unit (per year); T_m/population mean age when the first visible bone changes occur; RRBA/relative rate of bone aging = $(T_m - t_0)/T_m$.
[2] TMPJN/mean monthly temperature in January; VPJL/monthly mean humidity (partial vapor parcel pressure; hPa) in July; BISCR/bioclimatic index of severity of climatic regime; BISCRJL/the BISCR for July; DifBISCR/the differential parameter = BISCRJL − BISCRJN, reflecting the effect of interseasonal differences in the climatic conditions.

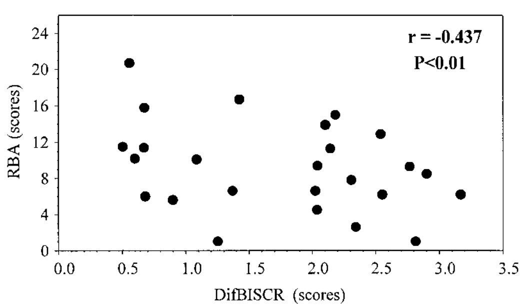

Fig. 2. Relationship between the RBA and seasonal rate of bioclimatic factors changes (DifBISCR).

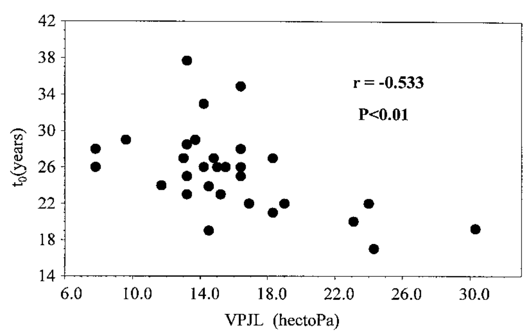

Fig. 3. Relationship between the earliest age of beginning of bone aging (t_0) and summer humidity (VPJL hectoPa).

almost any pair of the studied climate factors (Table 3).

Table 4 provides a multiple regression analysis of bone aging parameters on all climate variables that showed significant correlation (Table 2). Let us first consider the rate of bone aging and relative rate of bone aging indices. As seen in the table of six potential predictor climate factors, only one was retained in the regression equation, namely, DifBISCR (which reflects the extent of interseasonal differences in the climatic conditions). Some 19% of RBA variation was

attributable to this factor. This finding is of interest and importance, since it shows that, though daylight duration, mean temperature in the winter, or general comfort conditions in the summer months all showed significant relationship with RRBA as evinced in univariate correlation analysis (Table 2), their independent effect was rather negligible. This suggests that the time interval between the appearance of visible bone change in the first (probably most prone) individual and involvement of the entire population (T_m-t_0) in visible bone change depends not merely on climatic conditions per se, but rather also on the acuteness of their differences between seasons. This relationship was also evident when RBA estimates were plotted against DifBISCR (Fig. 2): note that the greater the difference in the comfort conditions, the narrower the gap between T_m and t_0.

Multiple regression analysis also revealed an independent contribution of July's humidity and January's mean temperature to t_0 (Table 4). These two variables explained about 32% of the total variation in t_0, and replaced unclear relationship between t_0 and geographic longitude (Table 2). Thus, multiple regression analysis clarified the relationship between t_0 and geographic longitude (Table 2, see also Livshits et al., 1996). The consistency of the relationship between t_0 estimates and VPJL illustrated in Figure 3.

Finally, note that only the index of comfort conditions in July was a significant predictor of q (Table 4), and no statistically significant correlation was detected between the rate of bone change once it became visible (parameter b) and any of the studied climate factors.

DISCUSSION

In a previous report (Livshits et al., 1996), we noted, inter alia, a specific correlation between age at the onset of bone aging (t_0) and the geographical coordinates of various studied ethnic groups. At that time, we attempted no explanation of the correlation for this necessitated incorporation of additional and novel climate factors into the analysis.

The present study, buttressed by a univariate analysis, now shows that t_0, again correlates significantly with longitude, yet there is also a significant correlation with the mean January temperature and humidity during both the summer and winter months. Multiple regression analysis, however, reveals that only TMPJN (mean monthly temperature in January) and VPJL (monthly mean humidity in July; hPa) independently affect t_0, which means that the effect of longitude can be completely explained by these two climatic factors alone.

Perhaps the most interesting finding of the present study is the detection of significant correlation between climatic characteristics and RBA and RRBA indices, which reflects the average time needed for the population to be involved in the beginning of bone changes. In other words, this correlation reflects the ability of the climatic differences to provoke the beginning of destructive bone changes. Yet, of the several climatic characteristics enumerated in Table 2, multiple regression analysis eschewed all but DifBISCR, which pertains to the difference in comfort conditions between summer and winter. To better understand the significance of this climatic index, we performed principal component analysis of matrix of pairwise correlations between climatic factors (see Table 3) and then multiple regression analysis of the DifBISCR (which reflects the extent of interseasonal differences in the climatic conditions) on climatic characteristics extracted in the first common principal component. Four variables, namely, TMPJN (mean monthly temperature in January), BISCRJL (Bioclimatic Index of Severity of Climatic Regime for July), VPJL (monthly mean humidity in July; hPa), and TMPJL (mean monthly temperature in July), explained about 90% of DifBISCR variation, with TMPJN alone contributing some 62%. Thus, both age characteristics (t_0 and RBA) of the onset of bone destruction are significantly related to the ambient temperature and humidity.

Temperature and humidity are basic climatic factors that directly effect a level of thermoregulation and, indirectly, affect activity of the circulatory system, including the basal metabolism rate and the various meta-

bolic processes (Hentschel and Turowki, 1988; Komarov et al., 1988; Bruce et al., 1991; Kenney and Buskirk, 1995; Scarpace and Matheny, 1996). It has further been shown that the inhabitants of diverse climato-geographical regions differ substantially in parameters of water–salt exchange, in their basal metabolism rate, and in their circulatory and endocrine functions (Nicolau et al., 1987; Bruce et al., 1991; Denofrio and Millikan, 1994). It follows, therefore, that the parameters of bone aging need not be considered merely as estimates of selective damage to the skeletal system, but should rather be regarded as a much broader reflection of the status of regulatory mechanisms monitoring the complex of aging changes in the organism. In this regard, the correlation dependencies between parameter t_0 and RBA on the one hand, and the temperature–humidity characteristics of the region on the other, represent important additions to our understanding of the possible causes for the onset of aging changes. As mentioned earlier, the climate characteristics DifBISCR defines summer–winter difference in the meteorological regime prevailing in any geographical locus inhabited by a specific population. From a bioclimatological standpoint, seasonal climatic contrasts as, for instance, between autumn and spring, produce particularly harmful effects on health, aggravating gastro-duodenal illnesses (Komarov et al., 1988), while those between winter and summer may facilitate asthmatic attacks in susceptible individuals (Deryapa, 1988; Sue-Chu et al., 1996). These seasonal differences in climate are probably also responsible for seasonal outbreaks of mortality from various kinds of morbidity (Hayek et al., 1987; Jones et al., 1994; Motohashi et al., 1996). During such transitional periods, the human organism is subjected to most unfavorable climate effects that "test" the reliability of regulatory systems. Failure, when it occurs, is usually in the weakest link of the regulatory system or else at the site (organ) affected by a pathological process.

Age-dependent, initial bone changes probably also conform to this pattern. In our opinion, the larger the differences in meteo-regime between the seasons, i.e., the higher the DifBISCR values, the less favorable are the conditions for bone metabolism and, consequently, the higher the probability for the early onset of bone destruction. The present data suggest that temperature and humidity are the key factors which trigger initial bone changes in sensitive individuals within human populations. The combination of these two, with other climatic factors which commonly reflect the extent of sharp contrasts between the seasons, predispose human populations to corresponding onset of bone changes.

LITERATURE CITED

Alexeeva TI (1977) Human biology and geographical environment. Moscow: 'Idea' (in Russian).

Beall CM (1994) Aging and adaptation to the environment. In DE Crews and RM Garruto (eds.): Biological Anthropology and Aging: Perspectives of Human Variation Over the Life Span. New York: Oxford University Press, pp. 339–369.

Beals KL, Smith CL, and Dodd SM (1983) Climate and evolution of brachycephalisation. Am. J. Phys. Anthropol. *62:*425–437

Beals KL, Smith CL, and Dodd SM (1984) Brain size, cranial morphology, climate, and time machines. Current Anthropol. *25*:301–330.

Belkin V (1992) Biomedical aspects of the development of mountain regions: A case-study for the Gorno-Badakhshan autonomic region, Tajikistan. Mountain Res Dev *12*:63–70.

Bruce N, Elfold J, Wannamethee G, and Shaper AG (1991) The contribution of environmental temperature and humidity to geographical variation in blood pressure. J. Hypertens. *9*:851–858.

Deryapa NR (1988) Bioclimatological aspects of human health and meteotropic diseases. In: Climate and Human Health. Leningrad: Proc. Int. Symp. WMO/WHO/UNEP, Vol. 1, pp. 68–82.

Dickinson RE (1970) Regional Ecology: The Study of Man's Environment. New York: John Wiley & Sons.

Denofrio LM, and Millikan LE (1994) Dermatoglyphic diseases of eastern Africa. Dermatol. Clin. *12*:621–628.

Goldberg E, Kobyliansky E, Kuperman S, and Pavlovsky OM (1993) The age osteometric status of Israelites. Vopr. Anthropol. *87:*80–86 (in Russian).

Hayek ER, Gittierrez JR, and Estinosa GA (1994) Seasonality of mortality in human population of Chile as related to climatic gradient. Int. J. Biometerol. *28:* 29–38.

Hentschel G, and Turowki E (1988) Classification of climate from a human biometeorological point of view both on a large and local scale. In: Climate and Human Health. Leningrad: Proc. Int. Symp. WMO/WHO/UNEP, Vol. 1, pp. 139–159.

Jones ME, Ponsonby AL, Dwyer T, and Gilbert N (1994) The relation between climatic temperature and sudden infant death syndrome differs among communities: Result from ecologic analysis. Epidemiology *5*:332–336.

Kenney NL, and Buskirk ER (1995) Functional consequences of sacropenia. Effect of thermoregulation. J. Gerontol. Series A, Biological Sciences and Medical Sciences *50*:78–85.

Kenney NL, and Hogson JL (1985) Heat tolerance, thermoregulation and aging. Sports Med. *4*:446–456.

Kobyliansky E, Livshits G, and Pavlovsky OM (1995) Population biology of human aging: Method of assessment and sex variation. Human Biol. *67*:87–109
Komarov FI, Rapoport SI, Eremina LV, and Kamrakov AV (1988) A chronological approach in the study of the influence of weather conditions on sick and healthy human being. In: Climate and Human Health. Leningrad: Proc. Int. Symp. WMO/WHO/UNEP, Vol. 2, pp. 33–36.
Livshits G, Vainder M, Pavlovsky OM, and Kobyliansky E (1996) Population biology of human aging: Ethnic and climatic variation of bone age scores. Hum. Biol. *68:*293–314.
Melton LJ, and Riggs BL (1987) Epidemiology of age-related fractures. In LV Avioli (ed.): The Osteoporotic Syndrome. New York: Grune & Stratton.
Motohashi Y, Takano T, Nakamura K, Nakata K, and Tanaka M (1996) Seasonality of mortality in Sri Lanka: Biometeorological considerations. Int. J. Biometeorol. *39:*121–126.
Nicolau CY, Haus E, Lacatva DJ, Bogdan C, Plinga L, Irvine P, Popesku M, and Petresku E (1987) Chronobiology of serum iron concentration in subjects of different ages at different geographical location. Endocrinology 25:63–82.
Pavlovsky OM (1987) Biological Age of a Man. Moscow. Russia: Moscow University Press.
Pavlovsky OM, and Kobyliansky E (1997) Population Biology of Human Aging. Firenze, Italy: Angelo Pontecorboli Editore.
Plato CC, Fox KM, and Tobin JB (1994) Skeletal changes in human aging. In DE Crews and RM Garruto (eds.): Biological Anthropology and Aging: Perspectives on Human Variation Over the Life Span. New York: Oxford University Press, pp. 272–300.
Pollitzer WS, and Anderson JB (1989) Ethnic and genetic differences in bone mass: A review with a hereditary vs. environmental perspective. Am. J. Clin. Nutr. *50:*1244–1259.
Scarpace PJ, and Matheny M (1996) Thermogenesis in brown adipose tissue with age: Post-receptor activation by forskolin. Pflugers Arch. Eur. J. Physiol. *434:*388–394.
Sue-Chu M, Larsson L, and Bjemer L (1996) Prevalence of asthma in young cross-country skiers in central Scandinavia: Differences between Norway and Sweden. Resp. Med. *90:*99–105.
Sokal RR, and Rohlf FJ (1981) Introduction to Biostatistics. New York: W.H. Freeman.
Smith K (1978) Principles of Applied Climatology. Leningrad: “”Hydrometeoizdat” (in Russian).
Walter SD (1992) The analysis of regional patterns in health data. II. The power to detect environmental effects. Am. J. Epidemiol. *136:*742–758.

APPENDIX A. Stochastic model parameter estimates age-dependent bone changes in male populations (according to Kobyliansky et al., 1995)

Group, geographic location[1]	Sample size	t_0[2]	q[2]	b[2]	T_m[2]	RBA[2]	RRBA[2]	Age
Abkhazians 1	340	25.0	0.049	0.469	45.6	20.7	45.295	18–99
Abkhazians 2	233	28.0	0.063	0.526	43.8	15.8	36.073	18–95
Azerbaijanians	131	26.0	0.087	0.512	37.4	11.4	30.481	19–88
Beduins	166	17.0	0.087	0.379	28.4	11.4	40.141	16–70
Buryats	125	27.0	0.118	0.667	35.5	8.5	23.944	20–56
Byelorus	76	29.0	0.081	0.582	41.3	12.9	30.788	22–80
Chukchi	73	26.0	0.086	0.566	37.6	11.3	30.295	19–60
Eskimos	48	28.0	0.161	1.000	34.2	6.2	18.129	17–61
Georgians	97	34.9	0.152	0.461	41.5	6.6	15.904	16–99
Indians	191	19.2	0.094	0.474	29.9	10.7	35.786	19–62
Jews	39	29.0	1.000	0.522	30.0	11.0	35.484	18–87
Karakalpaks	121	36.0	0.138	0.412	43.3	5.6	12.933	19–70
Karyki	52	33.0	0.161	0.466	39.2	6.2	15.816	18–62
Kazakhis	115	24.0	0.079	0.429	36.7	16.7	41.032	19–60
Lituanian	203	19.0	0.129	0.436	26.8	7.8	29.104	19–68
Mongols	99	26.0	0.107	0.321	35.4	9.4	26.554	23–78
Nents	74	25.0	0.107	0.650	34.3	9.3	27.114	17–78
Russian 1	269	26.0	0.149	0.523	32.7	6.6	20.245	19–60
Russian 2	209	22.0	0.100	0.571	32.0	10.1	31.464	17–85
Russian 3	85	23.9	0.223	0.396	28.4	4.5	15.845	22–83
Russian 4	60	22.9	0.123	0.839	31.0	9.2	29.114	22–60
Russian 5	117	23.0	0.388	0.456	25.6	2.6	10.156	21–90
Russian 6	34	22.0	0.070	0.476	36.2	15.0	40.541	22–84
Russian 7	79	27.0	1.000	0.484	28.0	1.0	3.571	20–79
Russian 8	78	23.0	1.000	0.437	24.0	1.0	4.167	18–63
T ajiks 1	108	27.0	0.166	0.367	33.0	6.0	18.182	19–57
Tajiks 2	56	28.5	0.099	0.694	38.6	10.2	26.357	20–78
Teke Turkmen	93	22.0	0.061	0.595	38.5	20.4	48.113	19–60
Yomut Turkmen	82	26.0	0.087	0.999	37.5	11.5	30.667	20–50
Tuvinci	177	21.0	0.129	0.601	28.8	7.8	27.083	19–71
Saamy	25	29.0	0.070	0.352	43.3	13.9	32.401	19–58

[1] Abkhazians 1 (Chlou, Jgerda, Atara); Abkhazians 2 (Kaldakhvar, Aatsy); Beduyins (Gebeliy, Aulad/said); Byelorus (Veremeiki); Karakalpaks (Karuzyak); Kazakhis (Akkol); Russian 1 (Argoda, Burguzin, Chitkan, Kurumkan Uro); Russian 2 (Azerbaijan); Russian 3 (Klaipeda, Palanga) Russian 4 (Kursk); Russian 5 (Peski); Russian 6 (Puttytino); Russian 7 (Voshod); Russian 8 (Ukhta); Tajiks 1 (Chorku); Tajiks 2 (Unji); Yomut Turkmen (Kulmach, Uzun-Su); Tuvinci (Chadan, Erzin, Toora-Jem).
[2] t_0/earliest age at which first signs of bone aging can be found; q/individual probability of revealing first signs of involutive bone changes assuming $t_i > t_0$; b/regression coefficient characterizing the rate of bone changes per chronological time unit; T_m/population ≥ mean age when the first visible bone changes occur; RRBA/relative rate of bone aging = $(T_m - t_0)/T_m$.

APPENDIX B. Climatic characteristics of the studies samples (according to Livshits et al., 1996)

Group, geographic location[1]	Latitude	Longitude	TMPJN	TMPJL	PRSJN	PRSJL	DIRJN	DIRJL	WNDJN	WNDJL	PRCPT	ALTTD
Abkhazians 1	43	41	+6	+22	1018	1008	W	ENE	2	2	1000	500
Abkhazians 2	43	41	+6	+22	1018	1008	W	ENE	2	2	1000	500
Azerbaijanians	41	45	−8	+22	1022	1010	W	W	2	2	1000	1000
Beduins	29	34	+12	+30	1018	998	ENE	NE	2	3	50	500
Buryats	54	110	−20	+16	1034	1006	WSW	E	3	3	250	400
Byelorus	54	31	−8	+18	1018	1010	N	E	1	1	600	200
Chukchi	67	170.0W	−16	+6	1014	1012	S	W	4	2	500	200
Eskimos	66	172.0W	−16	+6	1014	1012	S	W	4	2	500	200
Georgians	42	43	−2	+22	1022	1008	W	ENE	2	2	800	500
Indians	29	78	+12	+36	1018	1008	WSW	NE	2	4	500	500
Jews	32	35	+12	+28	1018	1006	ENE	ESS	2	2	100	200
Karakalpaks	43	60	−6	+26	1022	1010	WSW	SE	2	2	75	100
Kazakhis	43	71	−10	+26	1030	1002	WSW	SSW	3	2	100	500
Lituanian	55	23	−6	+18	1016	1012	NNE	ENE	1	2	500	100
Mongols	56	38	−10	+18	1020	1010	NNE	ESE	2	1	500	200
Nents	65	78	−26	+10	1018	1010	NNE	SE	2	1	500	200
Russian 1	54	110	−20	+16	1034	1006	WSW	E	3	2	250	400
Russian 2	41	48	−8	+22	1022	1011	W	NW	2	3	1000	500
Russian 3	55	23	−6	+18	1016	1012	NNE	NNE	1	2	500	100
Russian 4	51	36	−10	+18	1020	1010	NNE	E, SE	2	4	500	200
Russian 5	51	43	−10	+18	1020	1010	NNE	E, SE	2	4	500	200
Russian 6	53	40	−10	+18	1020	1010	NNE	E, SE	2	4	500	200
Russian 7	45	34	0	+22	1018	1010	W	SSE	2	2	250	200
Russian 8	64	54	−16	+10	1016	1010	NNE	SE	2	1	500	200
Tajiks 1	40	71	−12	+22	1026	1006	WNW	SE	2	3	300	1000
Tajiks 2	40	70	−4	+26	1026	1006	WNW	SE	2	3	300	500
Teke Turkmen	38	57	0	+28	1022	1010	WSW	SE	3	3	150	300
Yomut Turkmen	39	56	0	+28	1022	1010	WSW	SE	3	3	150	300
Tuvinci	51	94	−24	+12	1038	1006	NW	S	2	2	250	1000
Saamy	68	35	−12	+10	1010	1010	NE	SSW	3	3	400	300

[1] For each geographic location of sampled groups see Appendix 1.
For abbreviations of climatic factors, see Materials and Methods.

APPENDIX C. Climatic characteristics and bioclimatic indices of the studied samples not used in the previous study

Group, geographic location[1]	DAYJN[2]	DAYJL[2]	BISCRJN[2]	BISCRJL[2]	DifBISCR[2]	VPJN[2]	VPJL[2]
Abkhazians 1	10.25	15.75	6.138	6.695	0.557	0.3	16.4
Abkhazians 2	10.25	15.75	4.304	4.977	0.674	0.3	16.4
Azerbaijanians	10.75	16.00	5.230	5.900	0.670	0.3	16.4
Beduins	11.25	14.75	6.732	6.065	0.667	13.0	24.3
Buryats	9.00	18.00	5.076	7.979	2.903	0.8	18.3
Byelorus	9.00	18.00	7.393	9.932	2.540	2.6	13.7
Chukchi	6.50	22.00	6.364	8.506	2.142	1.4	7.8
Eskimos	6.50	22.00	5.954	8.506	2.552	0.9	7.8
Georgians	10.75	16.00	7.026	8.395	1.370	0.3	16.4
Indians	11.25	14.50	8.238	6.908	1.330	10.3	30.3
Jews	11.00	14.75	7.877	7.685	0.191	10.3	23.1
Karakalpaks	10.25	15.75	7.589	8.489	0.900	5.0	13.2
Karyki	8.50	20.75	5.500	8.668	3.169	1.6	14.2
Kazakhis	10.25	15.75	5.740	7.163	1.423	1.6	11.7
Lituanian	8.75	18.00	7.175	9.484	2.309	2.6	14.5
Mongols	9.75	16.50	4.273	6.316	2.043	5.2	15.0
Nents	6.50	22.00	6.620	9.388	2.768	0.6	13.2
Russian 1	9.00	19.00	4.421	6.445	2.024	1.6	14.2
Russian 2	10.75	15.75	6.371	7.459	1.088	4.0	19.0
Russian 3	9.00	19.00	7.157	9.193	2.037	2.6	14.5
Russian 4	9.75	17.25	7.391	9.397	2.007	2.4	19.0
Russian 5	9.75	17.00	7.346	9.690	2.344	3.2	15.2
Russian 6	9.50	17.00	6.584	8.766	2.182	5.4	24.0
Russian 7	10.00	16.50	8.177	9.432	1.254	5.4	14.8
Russian 8	6.50	21.50	6.166	8.981	2.815	1.2	13.2
Tajiks 1	10.75	15.75	4.686	5.367	0.681	4.7	13.0
Tajiks 2	10.75	15.75	5.897	6.496	0.600	5.0	13.2
Teke Turkmen	11.00	15.25	6.741	6.663	0.079	5.9	16.9
Yomut Turkmen	10.75	15.25	6.372	6.877	0.505	3.0	15.5
Tuvinci	9.75	17.75	3.760	6.103	2.342	0.8	18.3
Saamy	6.00	23.50	5.856	7.961	2.104	1.5	9.6

[1] For each geographic location of sampled groups, see Appendix 1.
[2] DAYJN/daylight duration (hours) in January; DAYJL/daylight duration (hours) in July; VPJN/monthly mean humidity (partial vapor parcel pressure; hPa) in January; VPJL/monthly mean humidity (partial vapor parcel pressure; hPa) in July; BISCR/bioclimatic index of severity of climatic regime; BISCRJN/the BISCR for January; BISCRJL/the BISCR for July; DifBISCR/the differentialparameter = BISCRJL − BISCRJN, reflecting the effect of interseasonal differences in the climatic conditions.